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Global Parameterization of Gravity Wave Temperature Perturbations for Chemical and Microphysical Models

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INTRODUCTION

The role of dissipating gravity waves in driving larger-scale circulations in the stratosphere is now well appreciated. Since gravity waves are still subgrid-scale processes in most global stratospheric models, considerable effort has been devoted to developing parameterizations of stratospheric gravity waves for them. Some parameterizations deal with large-amplitude waves generated from specific sources, such as mountains [e.g., *Palmer et al*., 1986] or convection [e.g., *Kersha*w, 1995]. Others parameterize the spectral evolution of the multi-wave fields more typically observed in the atmosphere away from source regions [e.g., *Fritts and Lu*, 1993; *Hines*, 1997].

It has become clear recently that gravity wave temperature perturbations can have significant effects on microphysics and chemistry [e.g., *Jensen and Toon*, 1994; *Meilinger et al*., 1995; *Murphy and Gary*, 1995; *Carslaw et al*., 1998; *Bacmeister et al*., 1998]. To include these influences within global models, effective parameterizations of the subgrid-scale temperature variability produced by gravity waves must also be developed. Here, we report of some recent efforts to parameterize various types of gravity-wave temperature perturbations, in forms that can be implemented relatively easily into global models of stratospheric microphysics and/or chemistry.

MOUNTAIN WAVE PARAMETERIZATION

The Naval Research Laboratory Mountain Wave Forecast Model (NRL/MWFM) was originally developed to forecast stratospheric turbulence produced by mountain wave breaking in the stratosphere, and thus aid safe flight planning during NASA aircraft campaigns. A full description of the operational model is given by *Bacmeister et al.* [1994] (see also http://uap-www.nrl.navy.mil/dynamics/html/mwforc.html). Briefly, dominant quasi-two-dimensional ridge structures are identified and characterized from high-resolution measurements of global topographic elevation. Global wind and temperature data are used to simulate isentropic flow over these ridges, which may force mountain waves locally. Hydrostatic wave equations, together with the upper-level wind and temperature data, are used to simulate any subsequent propagation and amplitude evolution of these mountain waves with height. In particular, simulated regions of wave-induced convective instability are identified, leading to global turbulence forecasts at various atmospheric pressure levels.

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NRL/MWFM can also be used to predict mountain wave temperature amplitudes *T'*. A standard isentropic advection analysis [e.g., *Eckermann et al*. 1998] yields

$$\frac{T'}{T_0} = \frac{N^2}{g}\zeta',$$

where T_0 is background temperature, N is the background Brunt-Väisälä frequency, g is gravitational acceleration and ζ' is the simulated mountain-wave vertical displacement amplitude at some location and pressure level. Figure 1b shows NRL/MWFM forecasts of mountain-wave-perturbed stratospheric temperatures T_0+T' on January 15, 1995. Open circles are regions 0-4K below frost point, solid circles show regions more than 4K below the frost point [*Carslaw et al*., 1998]. We note low temperatures over the northern end of the Scandinavian ridge, where a polar stratospheric ice cloud was detected during a flight campaign that day (Figure 1a).

We are actively assessing ways in which we can improve the NRL/MWFM parameterization for microphysical applications. For example, we are testing paramterization methods for three-dimensional topography and associated mountain wave patterns (see Figure 2). In particular, nonhydrostatic ray equations are now being used in test versions of the code to describe better the propagation of waves away from the mountain. Figure 3 compares one of these simulations (10th. Feb., 1989) with stratospheric ER-2 data obtained on that same day. The correspondence between simulated and observed activity is encouraging. We hope these new features will improve modeling *and* forecasting of mountain-wave-related processes in the stratosphere (e.g., during the SOLVE campaign in late 1999).

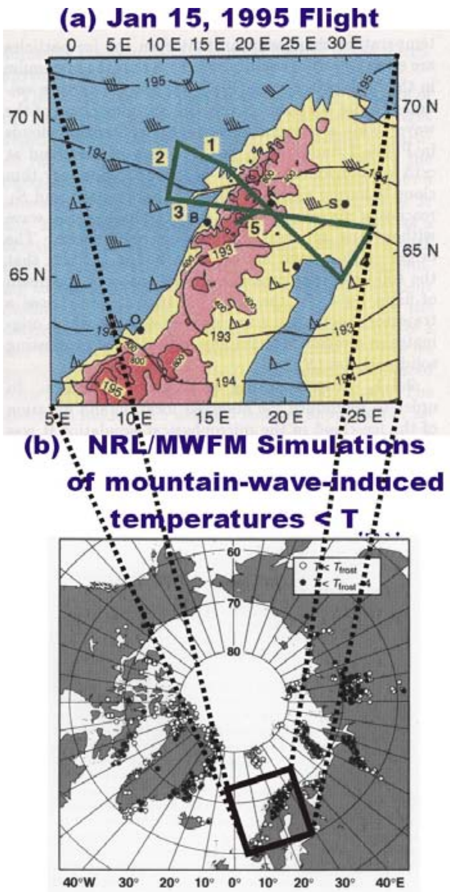

Fig. 1: (a) Jan 15, 1995 flight track during POLECAT mission, which detected strong mountain waves and a polar stratospheric ice cloud over the Scandinavian ridge; (b) NRL/MWFM simulations of mountain-wave-perturbed stratospheric temperatures for that day (region in (a) is boxed), with solid circles indicating values more than 4K below frost point, Adapted from *Carslaw et al.* [1998].

SPECTRAL PARAMETERIZATIONS

Away from intense sources, a quasi-constant level of "background" gravity wave activity is measured routinely in the atmosphere. Spectral analysis of this activity reveals that it has a well-defined spectral character that is largely independent of location or season. *Murphy and Gary* [1995] (MG95) analyzed the spectra of stratospheric temperature and heating/cooling rate fluctuations measured from aircraft, and argued that they had major perturbing effects on stratospheric microphysics.

Subsequently, *Bacmeister et al.* [1996] analyzed spectra of fluctuations measured from ~70 long-range ER-2 flights in the stratosphere. They found that the mean spectra

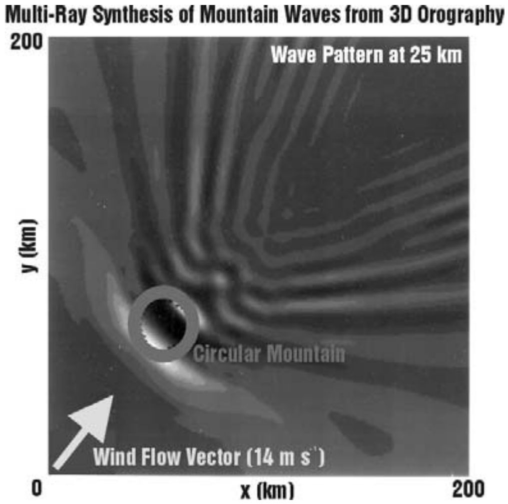

Fig. 2: Reconstructed mountain wave field at z=25 km produced by a circular mountain. Simulation was based on tracing an isotropic spectrum of 360 nonhydrostatic gravity waves, initially aligned across the mountain at various angles to the mean flow. Result resembles "ship wave" patterns seen in satellite imagery of mountain-wave clouds.

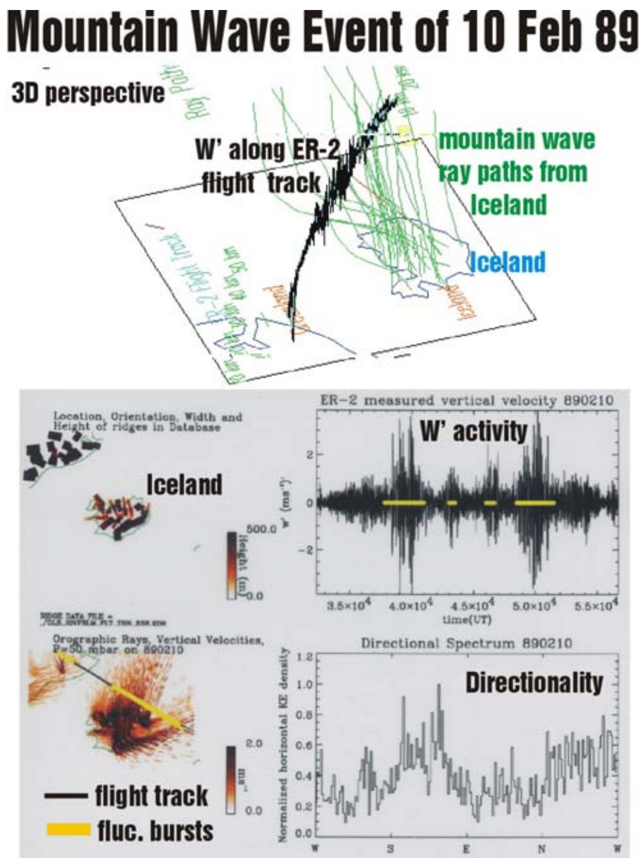

Fig. 3: Various 2D and 3D perspectives of enhanced vertical velocity activity measured on board the ER-2 aircraft as it passed near Iceland. Also shown are simulated nonhydrostatic mountain wave ray paths from Iceland for this day. The ray simulations successfully model observed locations and directionality of fluctuation bursts during the flight, indicating that the ER-2 intercepted stratospheric mountain waves downstream of Iceland.

were consistent with current separable models of gravity wave spectra and drag [e.g., *Fritts and Lu*, 1993]. *Bacmeister et al.* [1998] (B98) applied these findings to develop a spectrally-based parameterization of gravity-wave-induced temperature and heating/cooling rate fluctuations in the stratosphere, for use in microphysical calculations.

They compared the MG95 and B98 parameterizations by using both in a trajectory box model of stratospheric microphysics at various mean temperatures [*Meilinger et al*., 1995]. Instantaneous aerosol volumes as a function of temperature are shown in Figure 4 for each parameterization, based on realistic stratospheric values for the spectral parameters in each case. The MG95 spectral parameterization of mesoscale temperature variability gives much greater departures from equilibrium than the B98 model. Thus, spectral parameterizations disagree at present as to the amount of natural or "background" scatter in microphysical parameters due to background subgrid-scale temperature variability. *In situ* measurements of "natural" microphysical scatter may help to clarify the situation.

SUMMARY

Realistic computationally-cheap parameterizations of gravity wave temperature variability for microphysical applications represent a challenge for dynamicists. As in the

gravity-wave drag problem, we have attacked the problem to date from two angles. First, we have developed models of temperature perturbations due to large-amplitude mountain waves, which are known to have strong influences on stratospheric microphysics. Additionally, we have applied spectral theories of the wave field to parameterize the background gravity-wave temperature fluctuations that are encountered routinely in the stratosphere away from strong sources. Work in both areas continues.

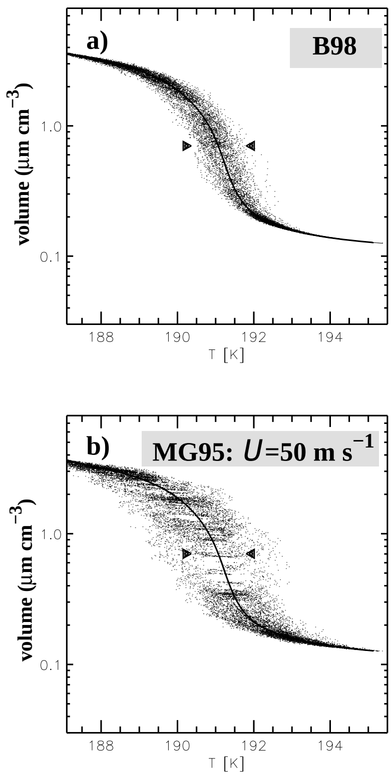

Fig. 4: Total aerosol volume versus temperature for the B98 and MG95 parameterizations, using the box-trajectory model of *Meilinger et al*. [1995]. Solid curves are results for thermodynamic equilibrium. Adapted from *Bacmeister et al.* [1998].

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